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Enhanced surveillance using speckle imaging (FY04 update)

CASIS: Signal and Imaging sciences workshop
November 18-19, 2004
Carmen J. Carrano
Lawrence Livermore National Laboratory

UCRL-PRES-208146
This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48

Acknowledgements

Dennis Silva : Real-time system integration / image subject
Doug Poland : Experiments
Mike Newman : Vehicle coordination for long-range imaging tests

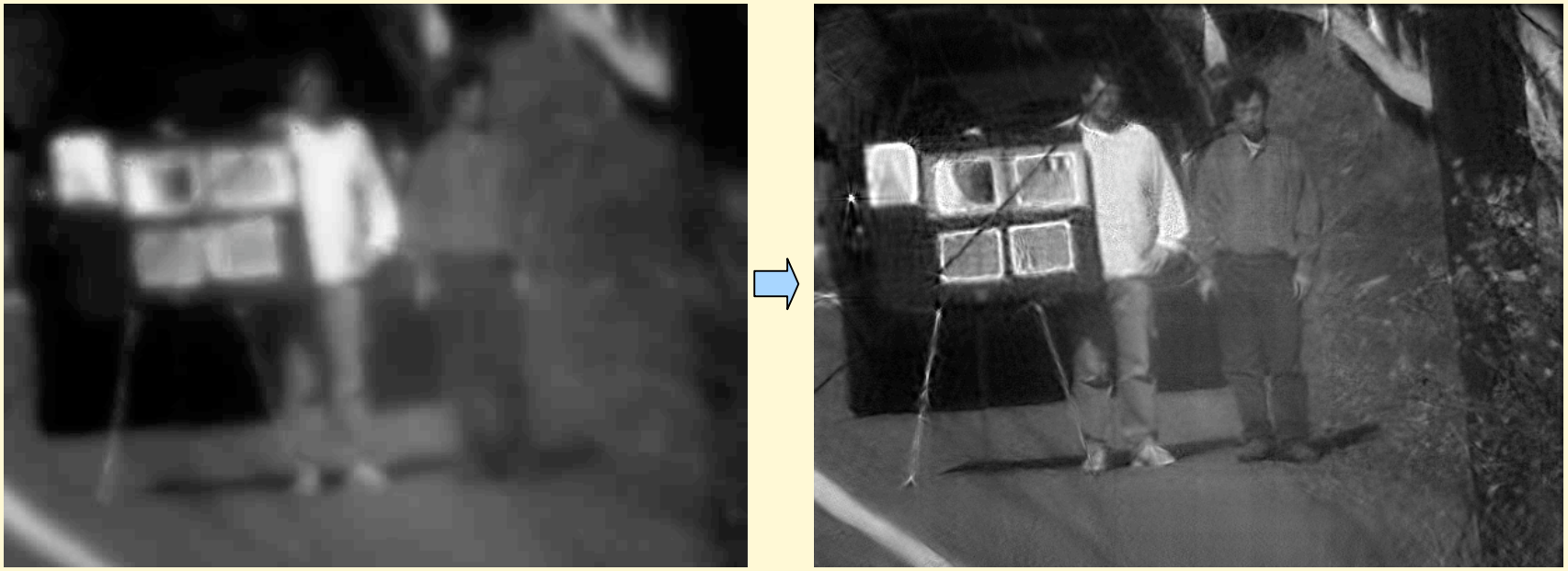
Kevin Baker : Experiment help / image subject (2001-3)
Brian Bauman : Optics / radiometry help
Kai LaFortune : Experiment help / image subject (2002-3)
Don Gavel : Consultant – simulations/atmospheric issues (2001-3)
Scot Olivier : Image subject (2001)
Jack Tucker: Image subject (2003)
Scott Wilks : Experiment help / image subject (2001-2)
Peter Young : Experiment help (2001-2)

Laura Klein (USAFA summer student - 2003) : Night experiment help
Karen Hanzi (Cfao summer student - 2002) : Experiment help / image subject
Miguel Montoya (summer student - 2001) : Image subject
LLNL security officers – Goforth & Kensic – night experiment image subjects

Funding: Engineering Techbase and DOE NA-22

What is Enhanced Video Surveillance?

- **Concept is to correct for atmospheric blurring and optical aberrations that reduce resolution and contrast in surveillance images recorded over long horizontal or slant paths.**
- **Improves resolution up to order of magnitude or more in scenes of interest, including personnel, vehicles and other objects for identification, at ranges from <1 km to >10's of km.**



Raw images **Enhanced image**

Range ~ 3.3 km

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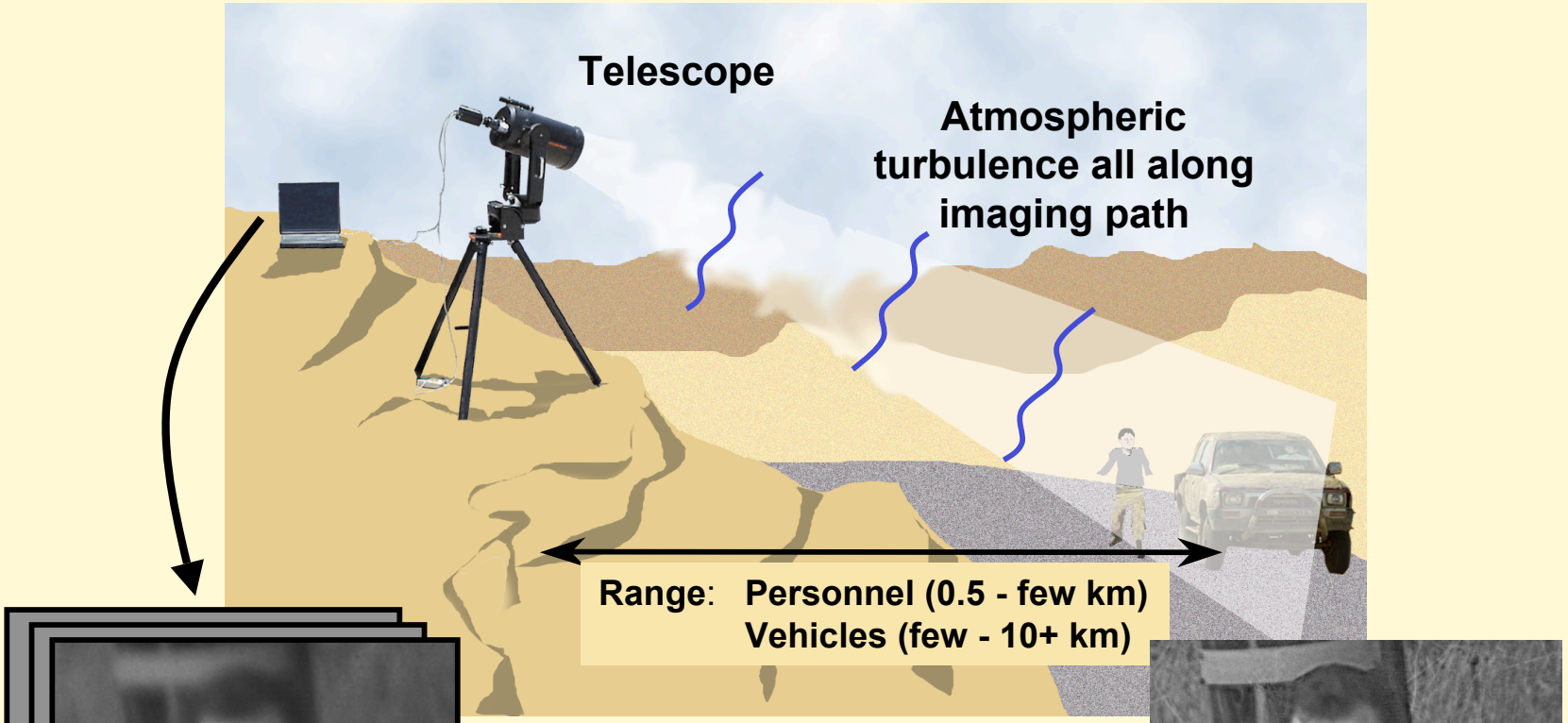
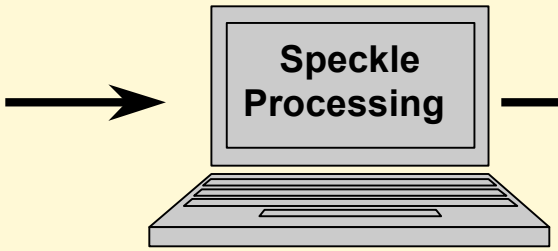
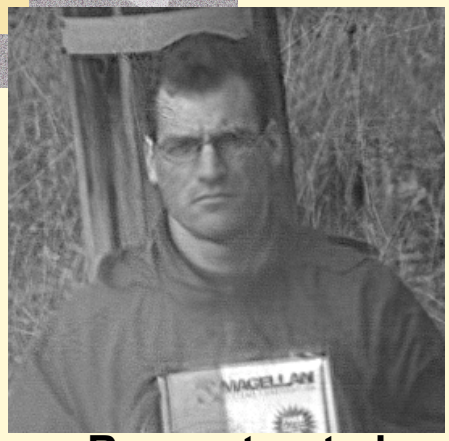
System diagram of typical horizontal/slant path setup



Time sequence of short exposure CCD camera images

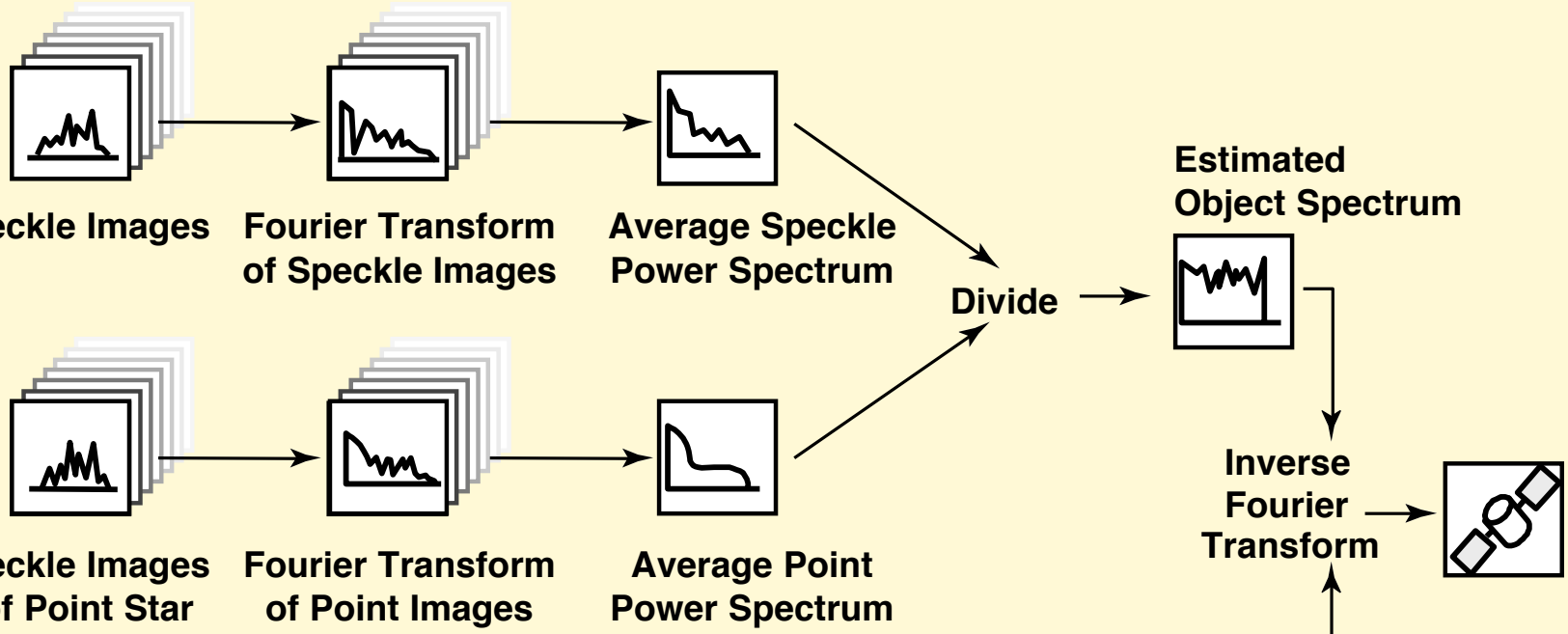




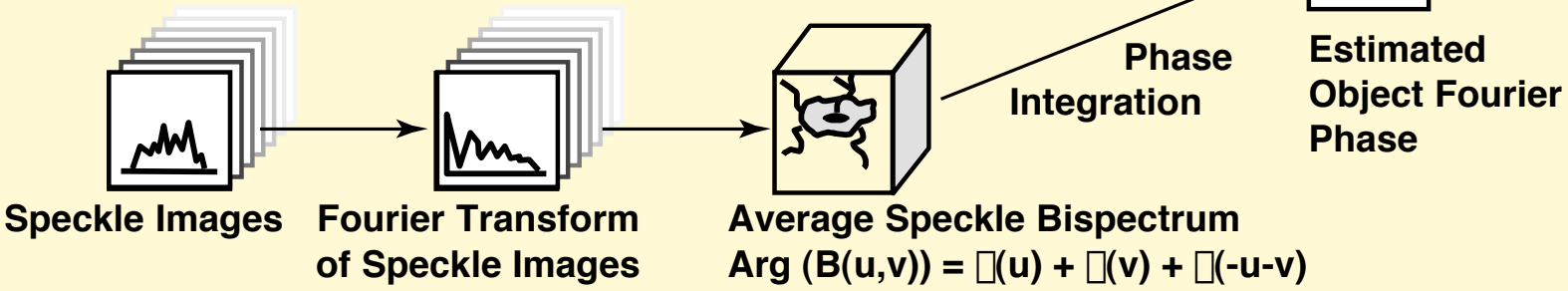
Reconstructed Image

The Fourier magnitude and phase can be estimated from speckle image sequences

- **Fourier Magnitude Estimate Using Speckle Interferometry**



- **Fourier Phase Estimate Using Speckle Masking**



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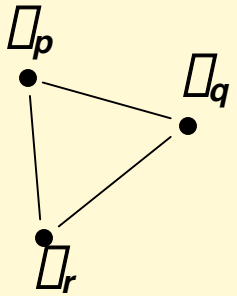
Averaging the bispectrum (also called a triple correlation) removes atmospheric phase errors



- Only terms with phases that satisfy phase closure contribute to the averaged triple correlation-

$$\phi_p + \phi_q - \phi_r = 0$$

and

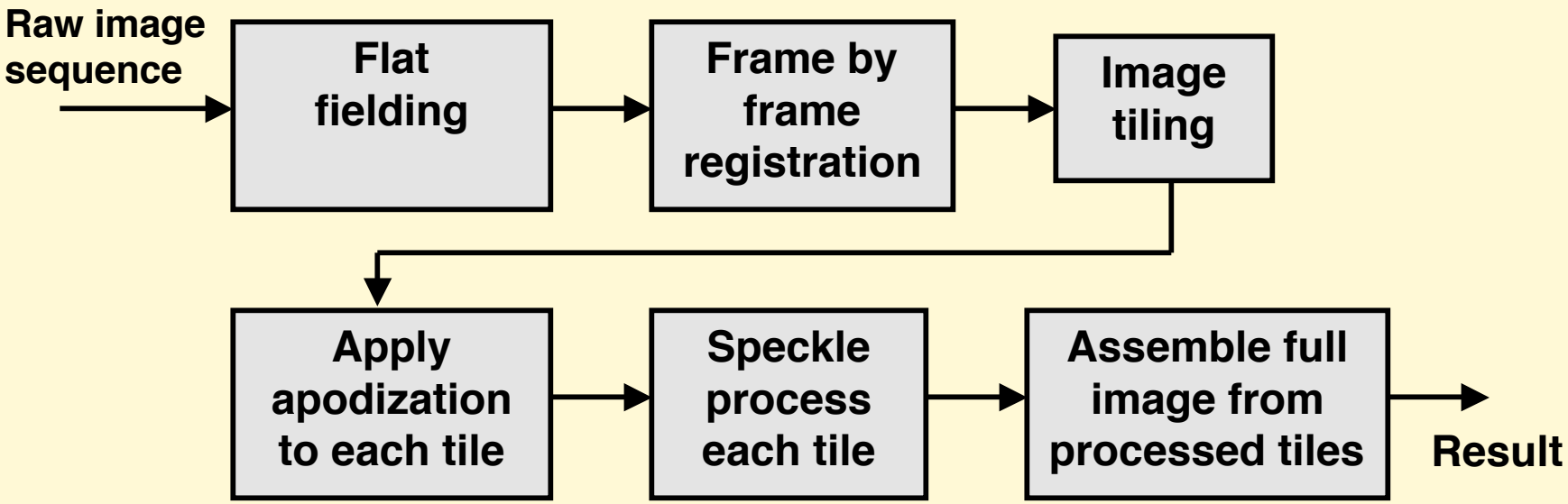
$$\left\langle e^{i(\phi_p + \phi_q - \phi_r)} \right\rangle = 1$$

- The average phase of the triple correlation due to *atmospheric turbulence* is zero i.e.- the triple correlation transfer function is real

- The phase of the average image triple correlation equals the object triple correlation phase ⟶ Phase recovery

Distributed turbulence correction requires space-variant bispectral phase estimation

- Scenes are extended - data doesn't fall to zero at the edges
  - Windowing needed
- No reference point source available
  - Atmospheric coherence length (r_o) is probably unknown so need to estimate it
- Phase estimation on local tiles
  - Need to process sub-regions and tile back together
  - Tile size is trade between isoplanatic patch and psf size
- Processing steps:

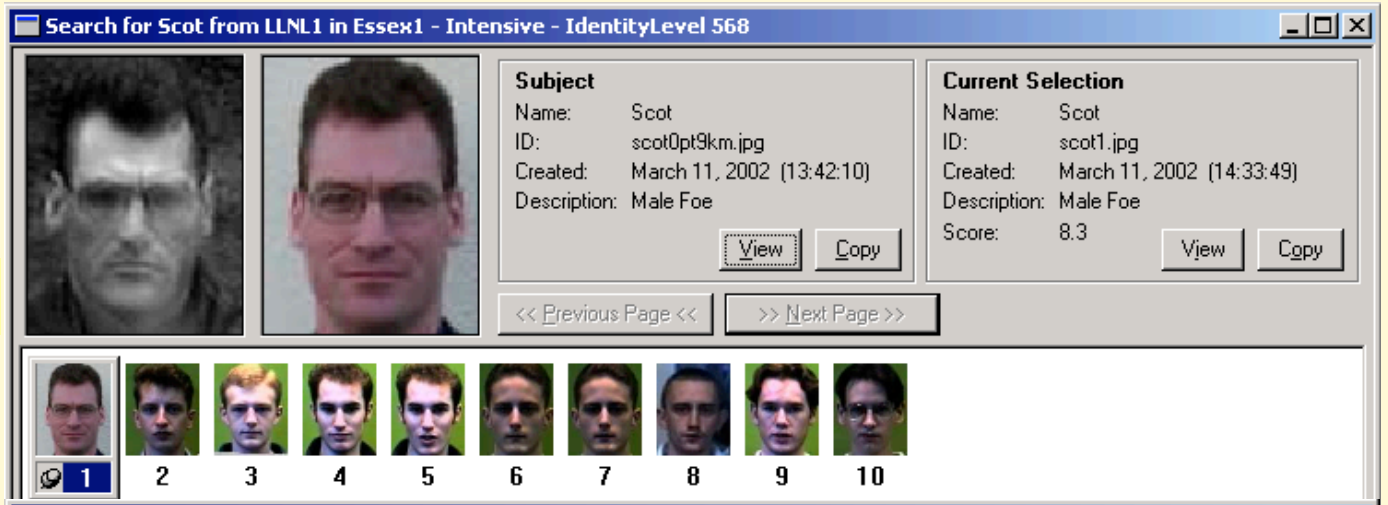


EVS enables facial recognition at long distances

Example case: Scot Olivier from 0.9 km
Results obtained searching a database of 685 people:

Using speckle reconstructed image

Correct match



Using shift and add image

Wrong match

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Demonstrated enhanced imaging of vehicles at long ranges

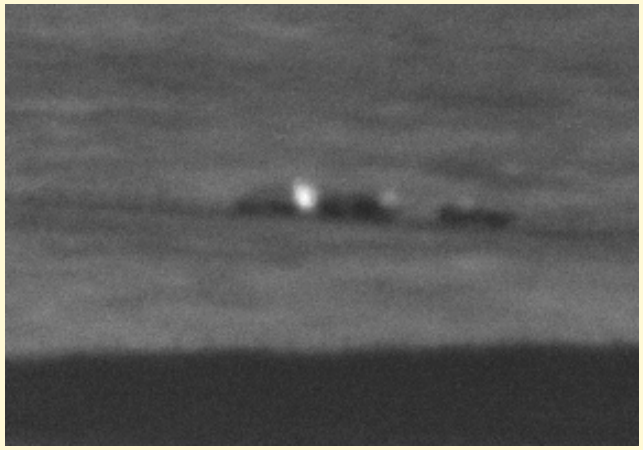
- Image 3 vehicles at varying ranges (20-40 km) from top of Mt. Diablo (elevation 3849')

- Experiment conditions:
  Temperature: cool
  Winds: light
  Visibility: ~1000' thick haze layer over the valley

Demonstrated enhanced imaging of vehicles at long ranges (~10-40 km)

- Imagery is of stationary vehicles acquired from the top of Mt. Diablo

Raw images | **Enhanced images**

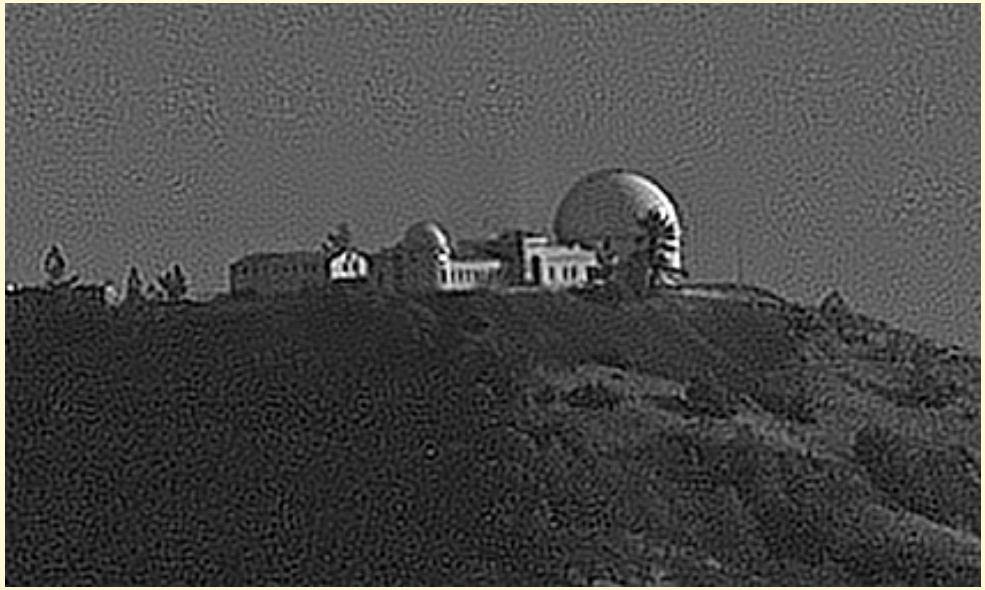


Range: 22 km

Range: 37 km

Lick observatory imaged from Mt Diablo
Range = 40 miles (60+ km)

Sample frame



Speckle processed

27.9 cm aperture
Exposure time: 1 ms
Flat-field gain correction
Used 256x256 pixel sized tiles,
DLmax = 306, proc. to DL= 30
r_0 = 1.5 cm (D/ r_0 = 18.6)

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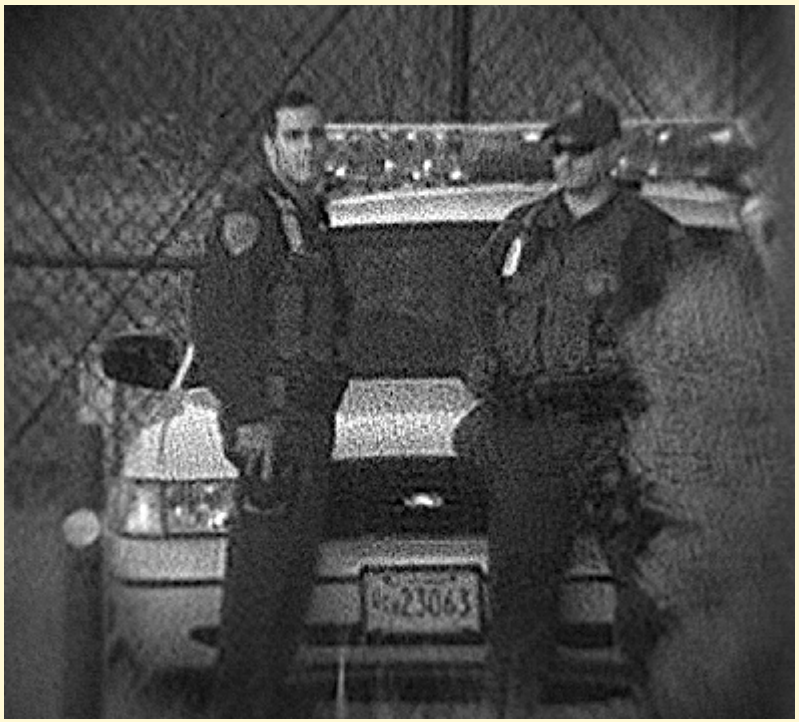
Demonstrated enhanced imaging at low light levels using an image intensifier coupled to the CCD camera.

- At twilight, the intensifier offers excellent system performance without active illumination, but for night-time viewing some sort of illumination is required.

1.5 km horizontal path at sunset

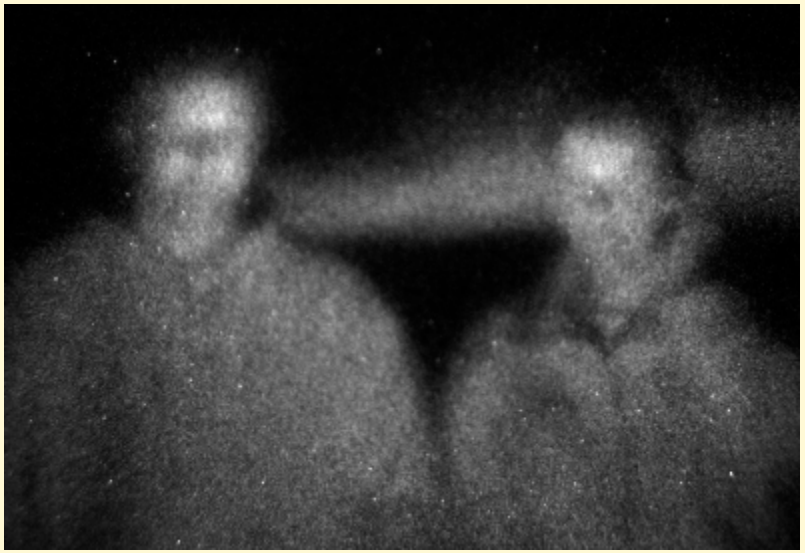
Raw image



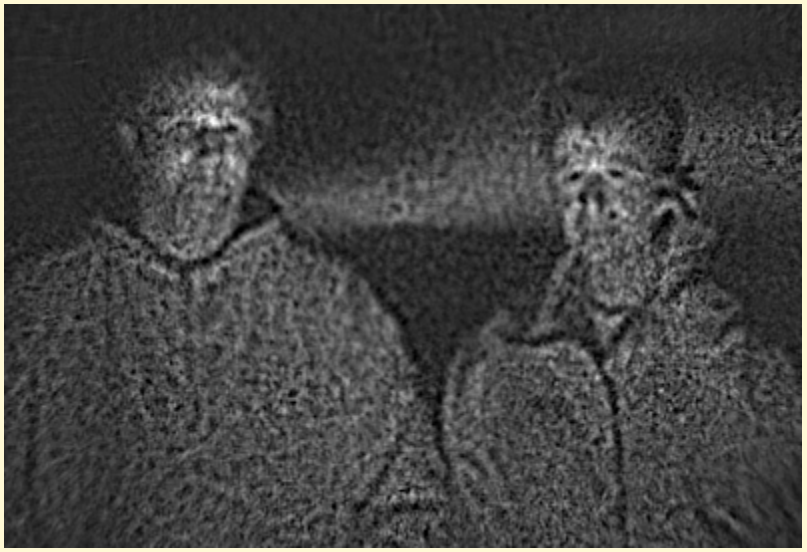
Enhanced image

Demonstrated enhanced imaging at night with active (covert) illumination

1.0 km horizontal path



Raw Image
Exposure time = 15 ms



Enhanced Image
Using 100 frames
r_0 = 2.0 cm, D/r_0=10

- **Used UF100 IR illuminator at 830 nm from 2 meters.**
  - **Estimated (peak) irradiance of targets is 6.4 W/m^2**
  - **Compare to solar irradiance of ~1000 W/m^2**

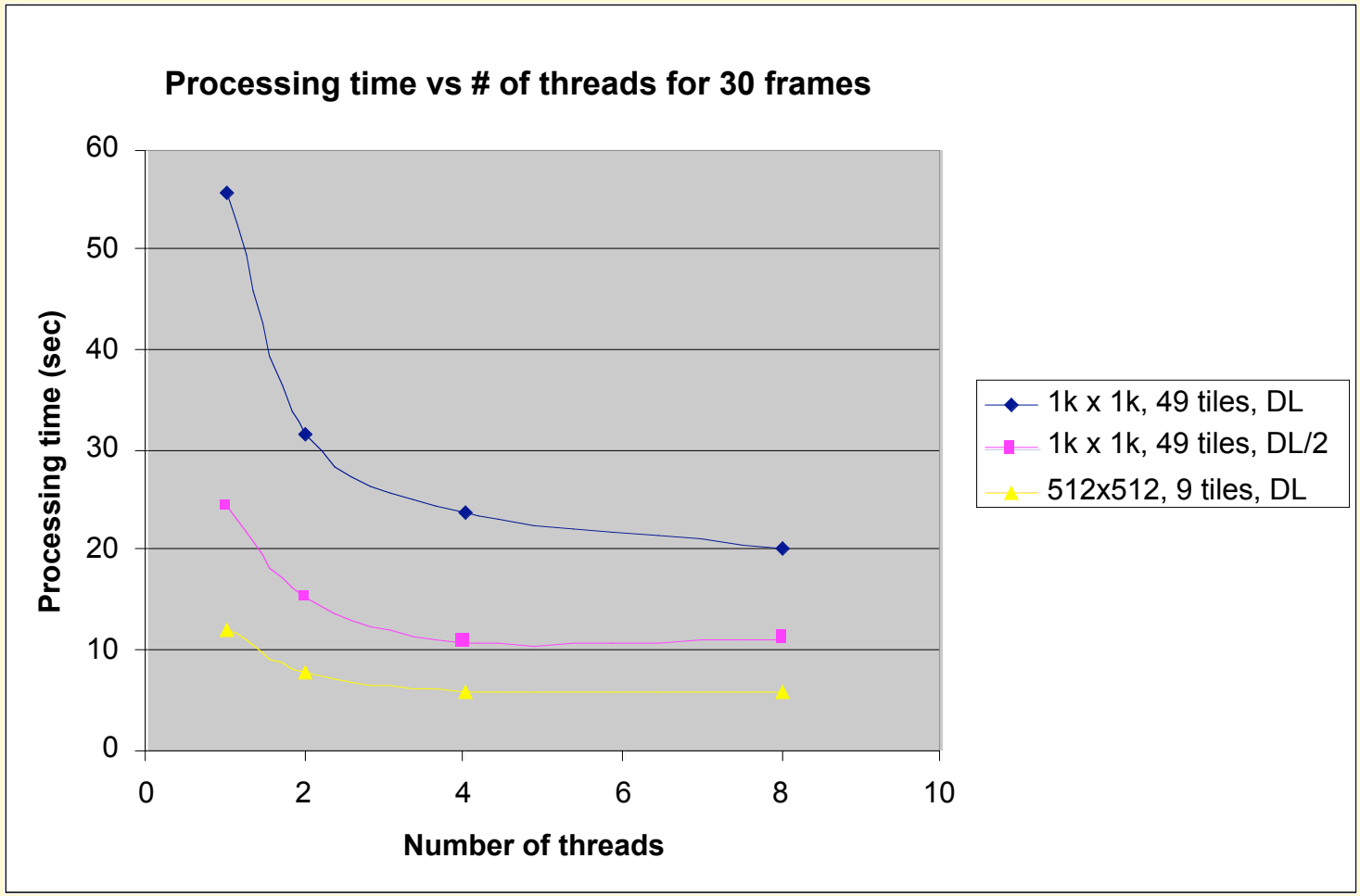
Enhanced Video Surveillance (EVS) highlights for FY04

- Parallelization of the speckle image processing software to take advantage of the multiple processors. User interface work. (TechBase)
  - Successful system test performed at Site 300 with semi-static targets (people)
  - On large images (with lots of tiles) we obtain roughly a factor of 3 speedup using 4 processors – it takes 20 seconds to process 30 frames of a 1k x 1k image

- Adapting the imaging processing technique to solve the *moving/translating target* problem (NA-22)
  - Can create simulated speckle data of moving vehicles/targets
  - Developed motion compensation pre-processing approach
  - Performed moving vehicle experiment from Mt. Diablo
  - Processed results look promising

On large images (with lots of tiles) we obtain roughly a factor of 3 speedup using all 4 processors.

Threaded version, where threading is done on tile operations up to and including the forward bispectrum
- Running on the Quad XEON (1.9 GHz) Linux machine

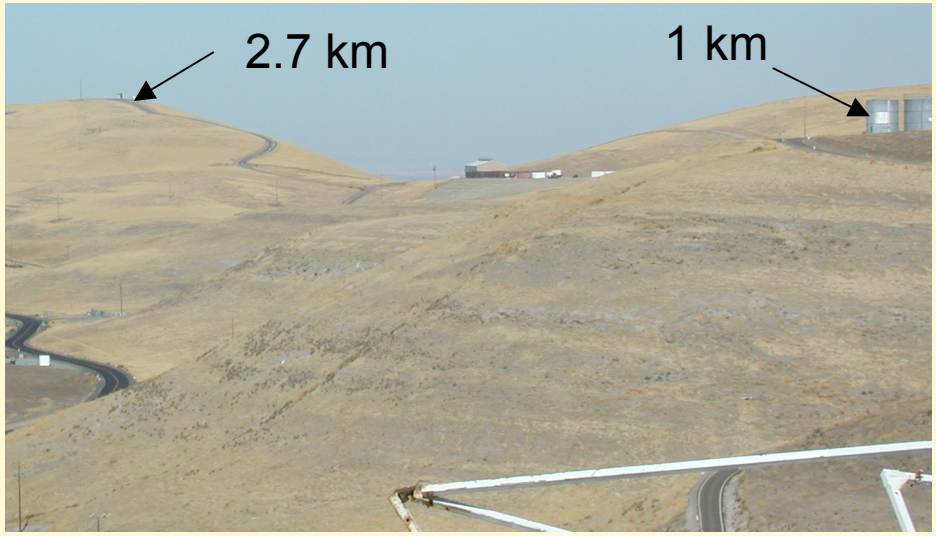


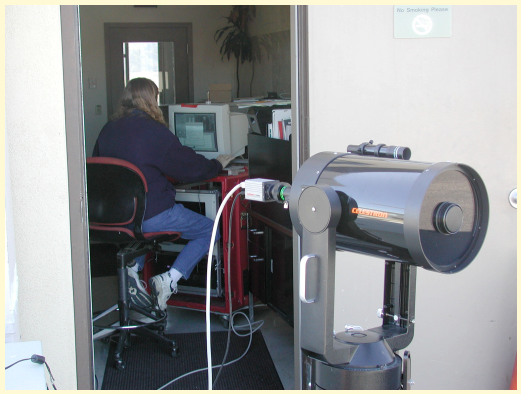
Demonstrated successful operation of real-time camera/system at Site 300 – Range = 1.0 km

Raw image

Enhanced image

- Can read shirts/hat
- Faces clear and recognizable





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Demonstrated successful operation of real-time camera/system at Site 300 – Range = 2.7 km

Jack holding radio. Dennis holding rifle prop.

Raw frame(s)

Speckle processed @r_0=1.2 cm from 40 frames

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Creation of simulated moving target speckle data

Acquired video imagery with real-time camera of car on street (no telescope).

- Apply atmospheric model
- Car region extracted out and centered in frames

Changing background creates image reconstruction artifacts that can completely obscure the target

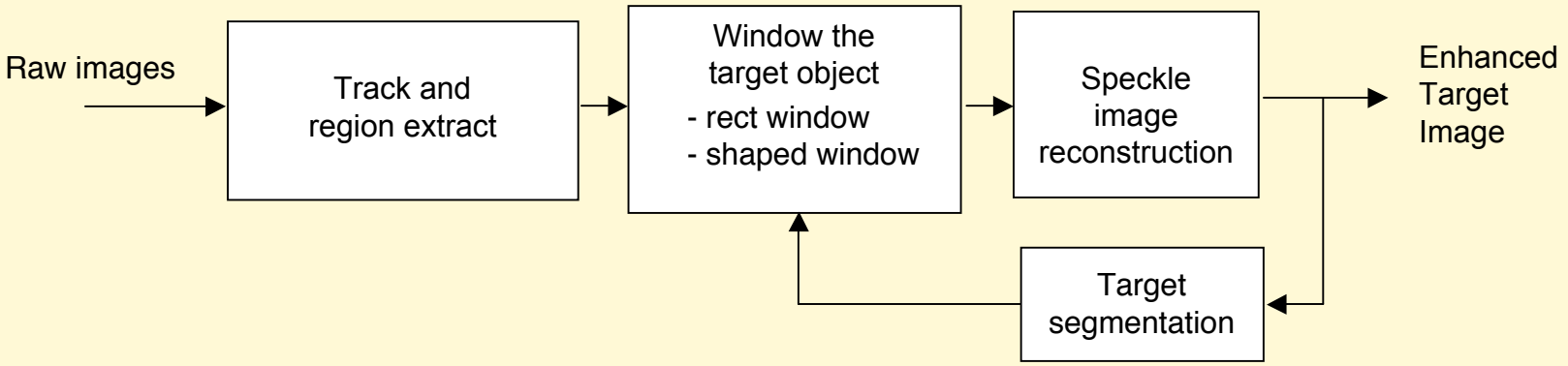
1st frame of car sequence

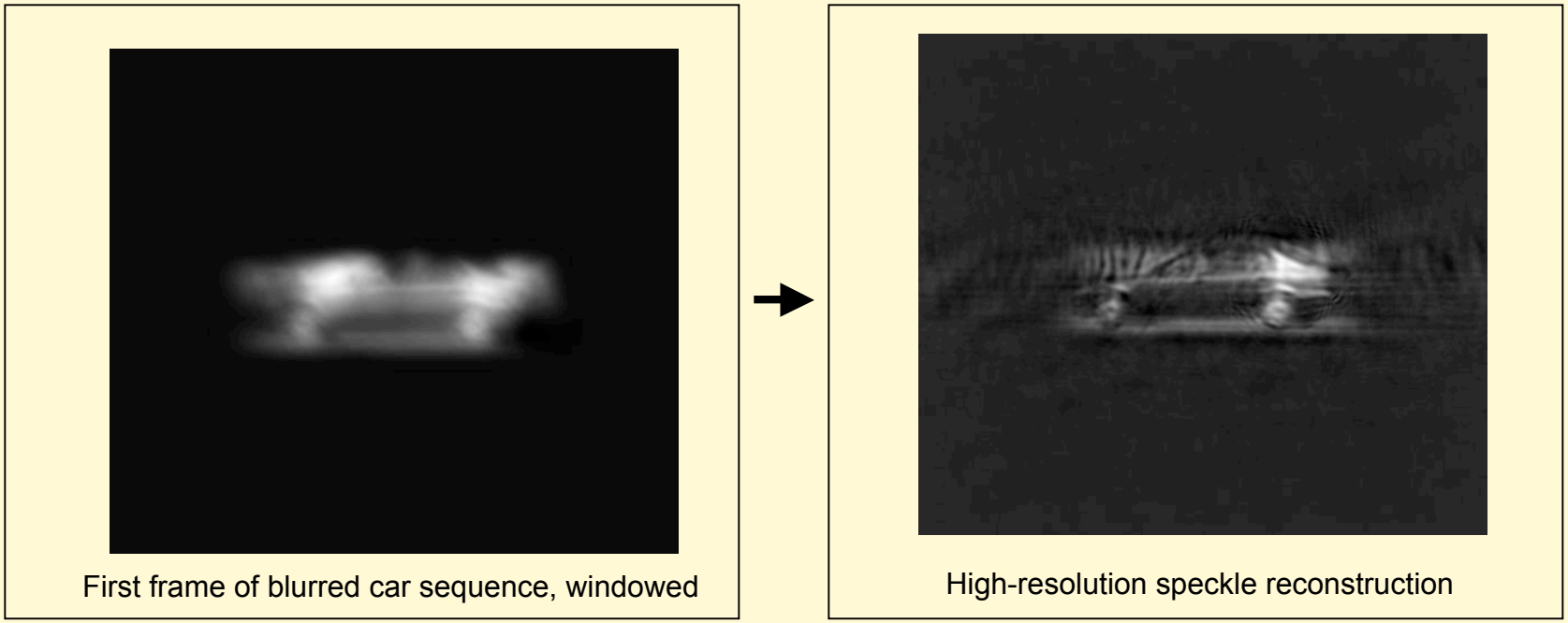
25th frame of car sequence

Speckle processed
Where's the car?

The motion compensation approach reduces artifacts by removing the background

Motion compensation algorithm





First frame of blurred car sequence, windowed

High-resolution speckle reconstruction

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From Mt. Diablo experiment: Reconstruction of a moving truck at 13 km range

Raw telescope imagery

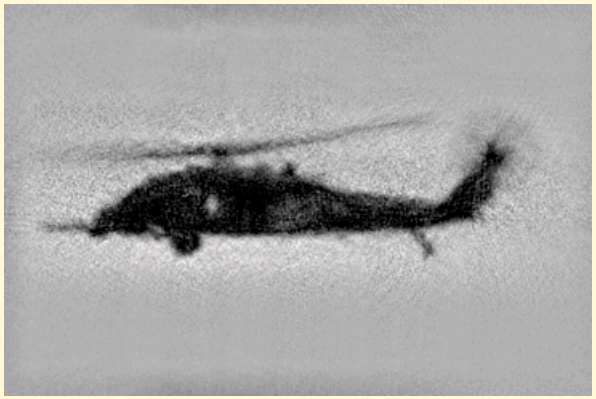
Simple addition of the registered frames

High-resolution speckle reconstruction result

Helicopter in flight over North Livermore

14 frames from raw data sub-region

Tracked, extracted, and windowed



Speckle processed

Raw data frames from stabilized camera mounted on an Aerostat at 2500 ft altitude in Yuma, AZ

- Data began as 8-bit RS170
- Saved to DV tape
- Manually extracted 120 frames
- Saved each in JPEG format!

Speckle processed imagery from a camera mounted on a stabilized platform on an Aerostat at YPG (Yuma, AZ)

Raw data frame
Altitude = 2500 ft

Speckle processed
120 frames
Used r_0=1.8 cm
Tilesize = 128x128

- This example demonstrates a potential link to Sonoma
  - Vehicles tracked with a wide angle sensor on a stabilized airborne platform.
  - Zoom in on targets of interest, use speckle processing to maximize resolution

Summary

- **We have developed and demonstrated a *unique capability* for long-range surveillance of personnel, vehicles and other structures from horizontal or low slant paths.**
  - **We have extended this capability to translating targets**

- **LLNL is working to attract new programmatic activities in DOD and Intelligence communities who need this capability. (e.g. DIA/MASINT, NorthrupGrumman, Army NVL, Special Forces, Aerostat applications, etc)**

- **Further related activities of interest**
  - ***Extend to longer wavelengths*** **(near-IR, IR) – *FY05 NA-22***
    - **Enhances connection to existing DOD tactical imaging and targeting systems**
  - **Continuous update/video-rate speckle**
  - **Rugged/compact/fieldable/non-expert systems**
  - **Vision science application : Speckle imaging into the eye**
  - **Full color speckle**